

# Design and Optimization of Cantilever Type MEMS Switches

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## Abstract:

This paper presents electromechanical design and simulation of cantilever type MEMS switches. The modelling approach is based on nodal analysis to solve coupled non-linear differential equations that describe the electromechanical system using a Matlab toolbox for MEMS (SUGAR). The switching voltage of mentioned construction for MEMS switches is determined and analysed at different geometrical parameters. The results show that the beam length, width, thickness and electrostatic gap dimensions, affect significantly on reducing the switching voltage  $V_{th}$ . These parameters are optimized to achieve a minimum threshold voltage and maximum switching frequency using genetic algorithm. The optimization process indicates that the switch can operate with threshold voltage of 7.2 V with maximum switching frequency of 453 MHz. Also the switch can give a maximum switching frequency of 2.83 GHz at 12.75 threshold voltage.

## 1. Introduction

The use of electrostatic MEMS switches is attractive because of its advantages, such as very low power consumption and high isolation. However, MEMS switches have their share of problems, such as, high driving voltage, relatively low speed and low power handling. In recent years many efforts have been done to solve these problems, e.g., decreasing the air gap between the fixed plate and the beam. Another method is to increase the electrostatic area or decreasing the spring constant of the beam [1]. In this paper we investigate the geometrical parameters of the structure and the electrostatic area of the gap that control the switching voltage to achieve a maximum frequency response for the switch at lower driving voltage. The structure of cantilever type MEMS switch is shown in figure (1).

## 2. Nodal Analysis Approach

SUGAR [2], is a collection of Matlab routines which implements a nodal analysis to Micro Electro-Mechanical Systems (MEMS) simulation. A wide variety of planner electromechanical systems can be simulated. SUGAR creates individual stiffness, mass, and damping matrices for each structural block. The equation of motion describing the dynamics of the entire system can be expressed in a familiar form [3],

$$M.\ddot{q} + C.\dot{q} + K.q = F \quad (1)$$

Where M, C, K are the mass, damping, and stiffness matrices respectively. The nodal displacement q is

$$\{q\} = \{x_1 y_1 \theta_1 \dots x_N y_N \theta_N\}$$

The q Matrix is 1x3N column vector and N is the number of nodes. F is the applied driving force.

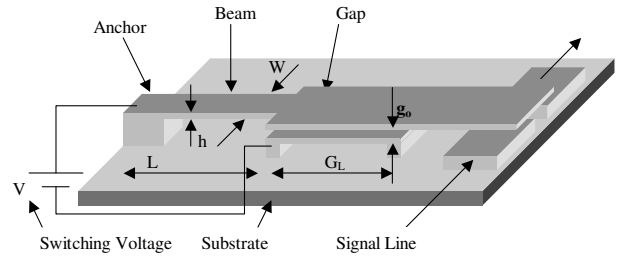


Figure (1): The Structure of Cantilever type MEMS switch.

### 2.1. Static Analysis

Static analysis attempts to find the equilibrium state for MEMS device with coupled energy domains [4]. These domains include mechanical forces, electrostatic forces due to a voltage from a circuit, forces due to thermal stress ...etc. The equilibrium position due to constant mechanical forces and voltages are calculated according to [5],

$$K.q - F = 0 \quad (2)$$

Solving equation (2) using Newton Raphson method, the initial guess  $\{q_0\}$  is taken which is sufficiently near a root, then approaches the solution by iteration. Iteration proceeds until certain tolerance is satisfied,

$$\|\{q_{n+1}\} - \{q_n\}\| < \xi$$

Where  $\xi$  is the tolerance.

### 2.2. Steady State Analysis

In the steady state analysis the following equation is solved [6-10],

$$M.\ddot{q} + C.\dot{q} + K.q = a_i \cos(\omega t + \beta_i) \quad (3)$$

Where  $a_i \cos(\omega t + \beta_i)$  is the sinusoidal external excitation.

The solution of this equation is the real part of the following complex equation,

$$M.\ddot{z} + C.\dot{z} + K.z = \beta_i e^{j\omega t} \quad (4)$$

Where

$$\beta_i = a_i (\cos \beta_i + j \sin \beta_i)$$

A particular solution of equation (4) is,

$$Z = \{V\} e^{j\omega t} \quad (5)$$

Where V is a complex vector that contains the magnitude information of the system response. Substituting equation (5) into (4) to get,

$$-\omega^2 .M + j.\omega C + K.V = \{B\} \quad (6)$$

Once equation (6) is solved, the magnitude and phase response for each node is evaluated. The steady state vibration of the structure can be investigated.

### 3. Design of Cantilever Type MEMS Switch

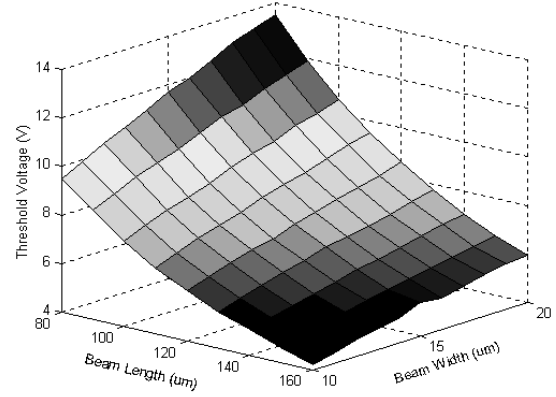
The cantilever type MEMS switch shown in figure (1) is modelled as anchor, beam, electrostatic gap, switching beam, and two isolated beams for signal line. Material and geometrical parameters of the structure are illustrated in table (1). The switching beam is electrically isolated from the upper plate of the gap.

### 4. Simulation Results

#### 4.1. static Analysis

The structure of the cantilever type MEMS switch is simulated under applied voltage V between the two plates of the electrostatic gap. The displacement of the switching beam at node F is calculated. The voltage is tuned to satisfy the switching-on between the two signal line beams. This voltage is called threshold voltage  $V_{th}$ . It is calculated at different selected geometrical parameters of the structure.

Figure (2) shows the reflection of choice of different beam lengths and widths on the threshold voltage. The results show that at low values of beam widths the threshold voltage is lower than that at higher values, but almost the threshold voltage decreases with increasing the beam length.



**Figure (2):** The threshold voltage vs. beam length at different values of beam widths.

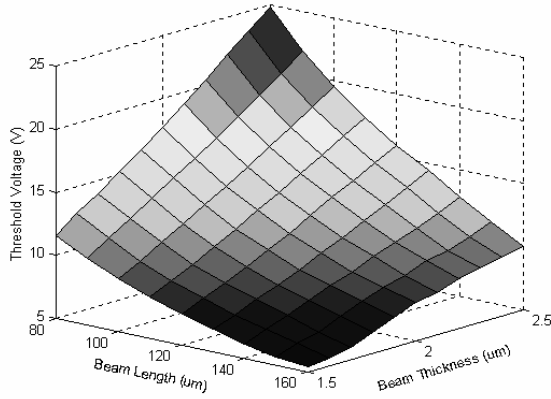
**Table (1):** The Material and geometrical parameters for cantilever type MEMS switch:

Parameter	Value
Material	Polysilicon
Poisson's ratio	0.3
Young's modulus	1.65E11 N/m <sup>2</sup>
Sheet resistance	20 Ω/
<b>Anchor</b>	
Length	20 μm
Width	20 μm
Thickness	8 μm
<b>Beam</b>	
Length (L)	80 : 160 μm
Width (w)	15 μm
Thickness (h)	1.5 : 2.5 μm
<b>Gap</b>	
Length (G <sub>L</sub> )	30 : 60 μm
Width (W <sub>G</sub> )	30 μm
Upper plate thick.	1.5 μm
Lower plate thick.	1.5 μm
Air gap thick.	1.5 : 2.5 μm
<b>Lower anchors</b>	
Length	10 μm
Width	30 μm
Thickness	5 μm
<b>Switching beam</b>	
Length (L <sub>S</sub> )	75 μm
Width	30 μm
Thickness	1.5 μm
<b>Signal line beam</b>	
Length	30 μm
Width	90 μm
Thickness	7 μm

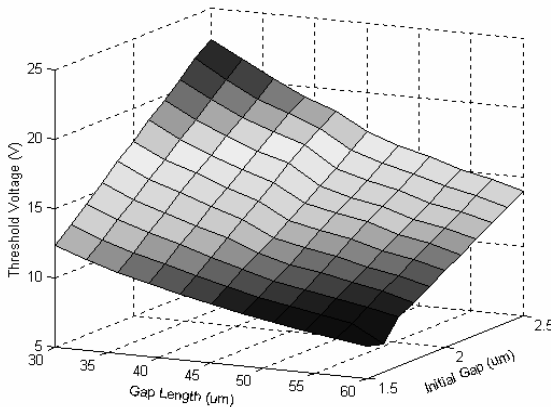
Figure (3) shows the reflection of choice of different beam lengths and widths on the threshold voltage, from figure (3) it is notice that the threshold voltage is increased more than double of its value at the highest

values of beam thickness. Thus we propose the lower values of beam thickness to decrease the threshold voltage required for switching on.

Figure (4) presents the effect of electrostatic gap length and air gap thickness on the threshold voltage of the switch. It is useful to use the lower values of air gap thickness and higher values of gap length to satisfy a lower threshold voltage  $V_{th}$ .



**Figure (3):** The threshold voltage vs. beam length at different values of beam thickness.



**Figure (4):** The threshold voltage vs. gap length at different values of air gap thickness.

## 5. Optimization Process

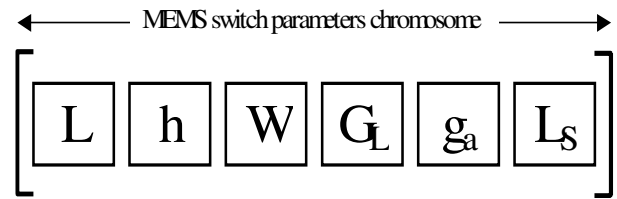
Genetic algorithm has been used to optimize the MEMS switch parameters by changing its geometrics namely, beam length ( $L$ ), width ( $W$ ), thickness ( $h$ ), gap length ( $G_L$ ), Air gap thickness ( $g_a$ ) and switch beam length ( $L_s$ ). Binary encoding scheme is used in this algorithm to encode the MEMS switch parameters [11-12].

The chromosome contains all parameters as shown in Fig.5. Each gene parameter encoded as 4-bit to include sixteen quantized values, as shown in Fig.6. Elitism is used to save the best solutions to improve the performance of the genetic algorithm [12]. The algorithm is started with a set of solutions (represented by chromosomes) called population. Solutions from one

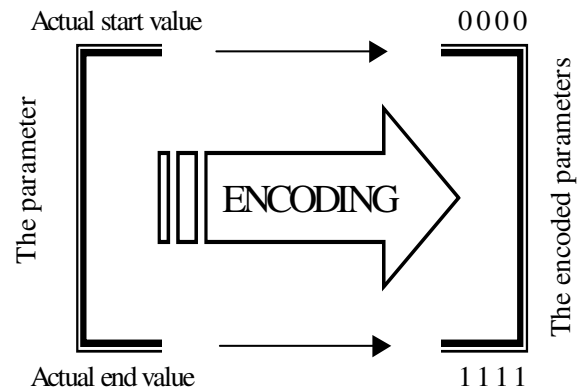
population are used to form a new population. This is motivated by a hope, that the new population will be better than the old one. Solutions that are selected to form new solutions (offspring) are selected according to their fitness. The more suitable they are the more chances they have to be reproduced. This is repeated until some conditions (for example number of populations or improvement of the best solution) is satisfied. The genetic algorithm proceed as follows, [11]

- (1) Create a population of random individuals which represents a possible solution to the problem at hand.
- (2) Evaluate each individual fitness i.e. its ability to solve the specified problems.
- (3) Select individual population members to be parents.
- (4) Produce children by recombining parent's material via crossover and mutation and add them to the population.
- (5) Evaluate the children fitness.
- (6) Repeat steps (3-5) until a solution with the desired fitness goal is obtained [13-14].

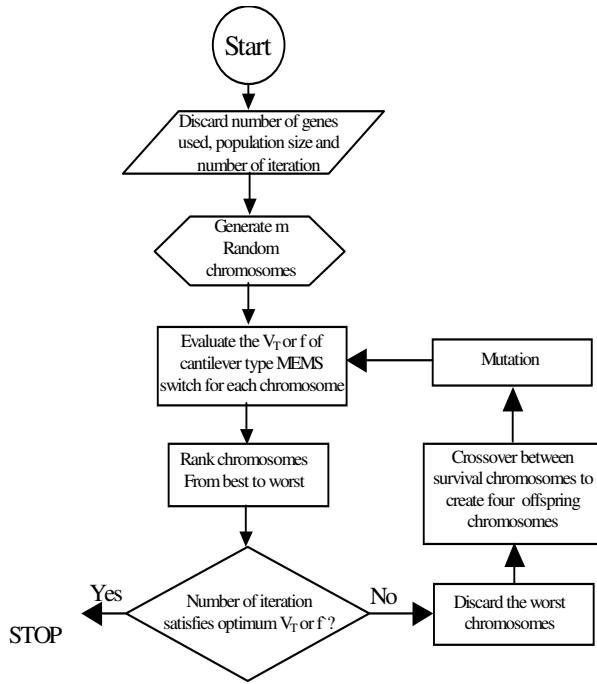
The genetic algorithm flow chart of the optimization problem is shown in Fig.7.



**Figure (5):** The structure of MEMS switch parameters chromosome.



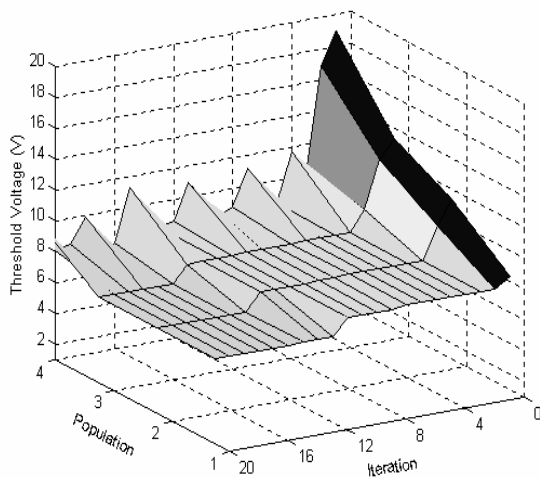
**Figure (6):** The binary encoding of MEMS switch parameters



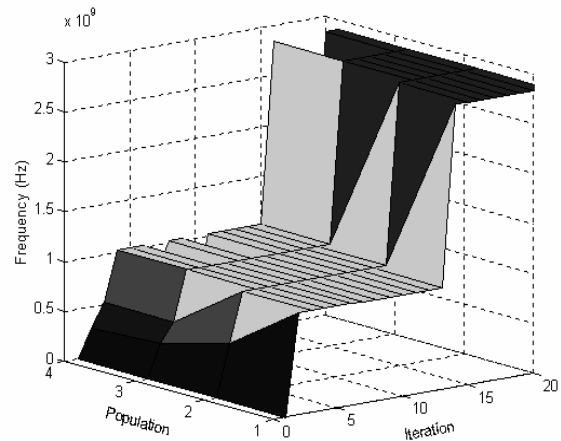
**Figure (7):** The flow chart of the genetic algorithm

## 6. Optimization results

The optimization process proceeds to obtain the minimum threshold voltage of the cantilever type MEMS switch by optimizing the geometrical parameters. The optimization process depends on the number of iterations needed to achieve the minimum threshold voltage of the switch. After 20 iterations (Fig.8), the voltage reaches a minimum steady state value of 7.2 V. Table 2. Shows the parameters required to achieve this voltage. The table also includes the parameters required to optimize for maximum frequency response for the switch. Figure (9) shows the optimization process for maximum frequency response.



**Figure (8):** The optimization process for minimum threshold voltage



**Figure (9):** The optimization process for maximum frequency response

**Table (2):** The geometrical parameters for Optimum threshold voltage and Optimum frequency response.

Parameter ( $\mu\text{m}$ )	Optimum threshold voltage	Optimum frequency response
L	150	110
h	1.5	1.5
W	10	13
$G_L$	65	45
$g_a$	1.6	1.5
$L_S$	75	30
Trade-off parameters	$V_T = 7.2 \text{ V}$	$V_T = 12.75 \text{ V}$
	$f_{\text{cut}} = 453 \text{ MHz}$	$f_{\text{cut}} = 2.83 \text{ GHz}$

## 7. Conclusion

In this paper we investigate the geometrical parameters of the structure and the electrostatic area of the gap that control the switching voltage to achieve a maximum frequency response of the switch at lower driving voltage.

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